

Titanium coatings deposited by thermal spraying for bipolar plates of PEM electrolyzers

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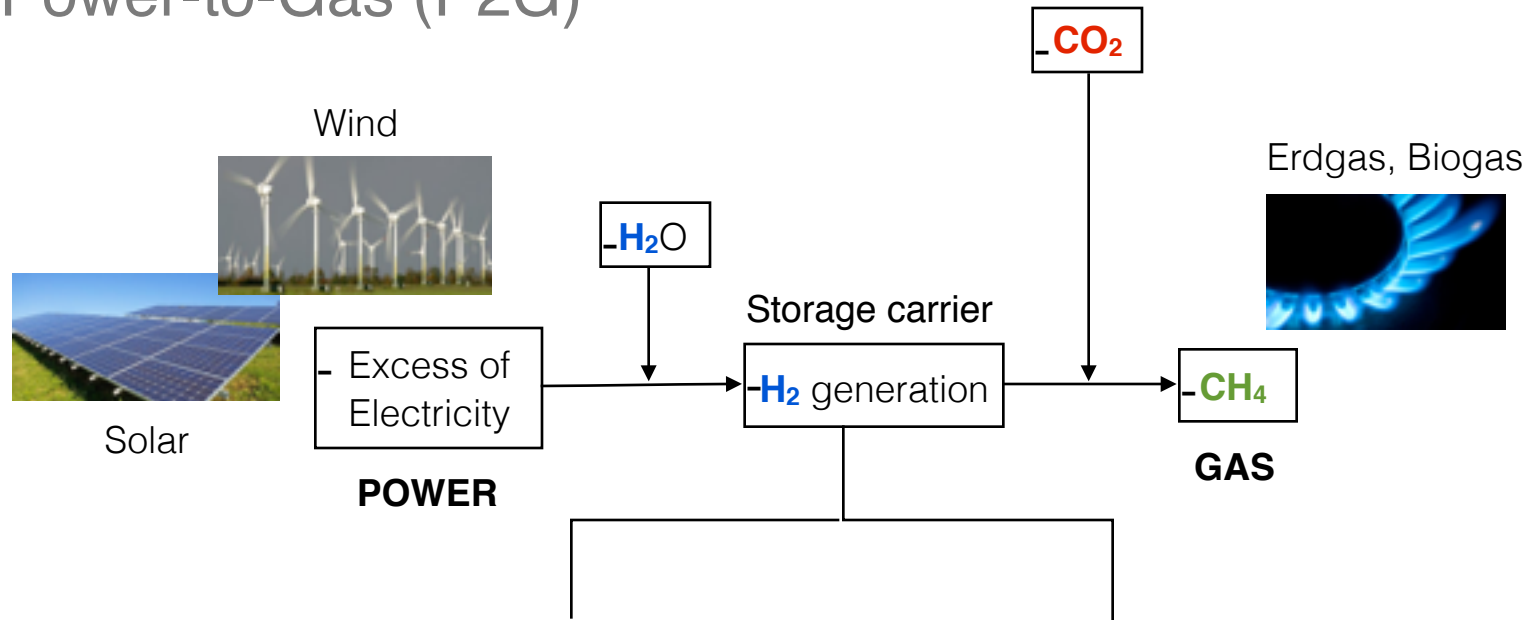
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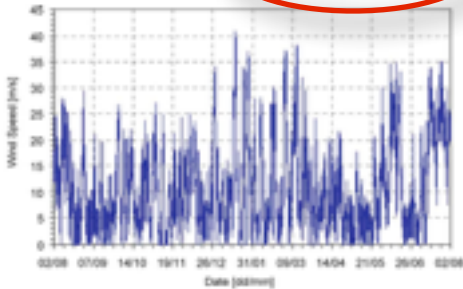
Knowledge for Tomorrow



Power-to-Gas (P2G)



Wind profile: **Intermittent**



Alkaline electrolysis

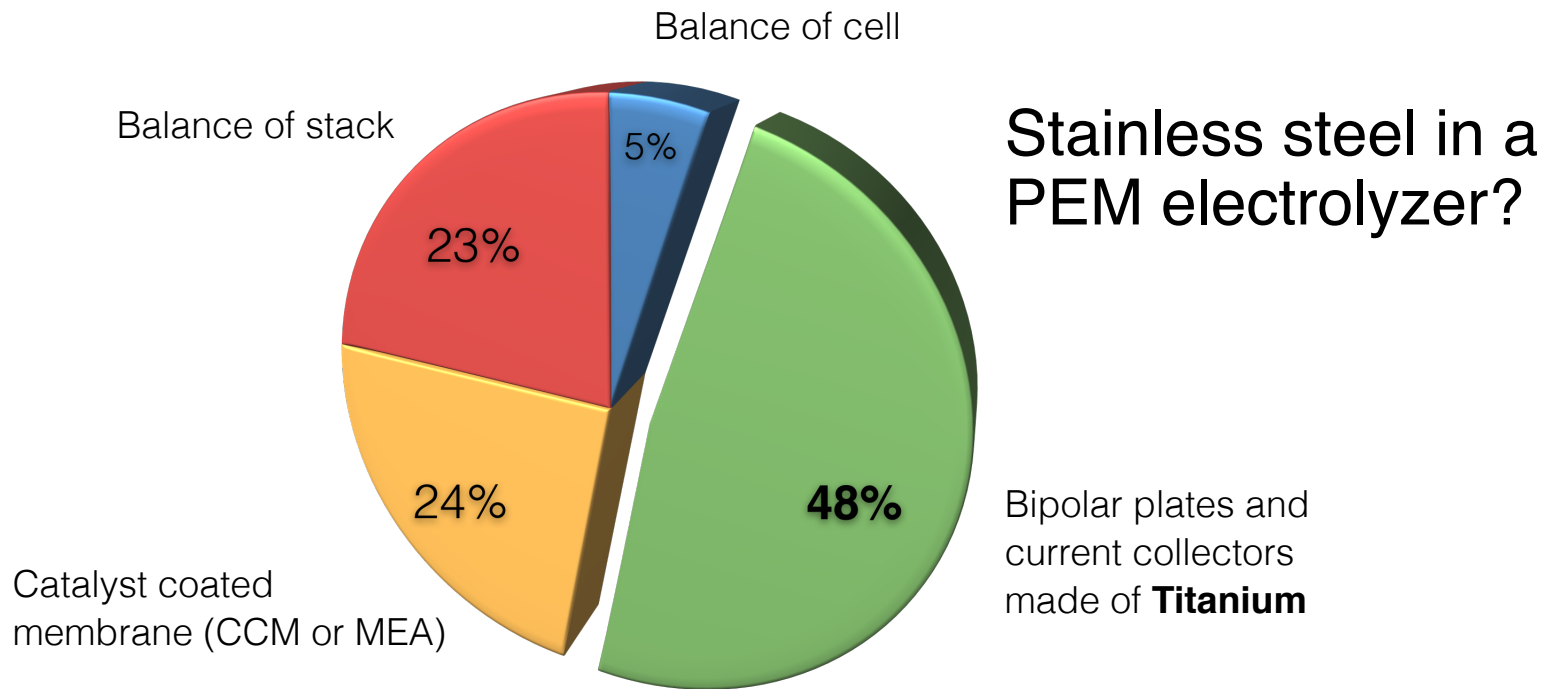
- Liquid electrolyte (KOH)
- Additional compressor
- $< 0.4 \text{ A cm}^{-2}$
- Slow response
- Cheap

PEM electrolysis

- Uses only DI water
- No additional compressor
- $> 10 \text{ A cm}^{-2}$ (expected)
- Rapid response (dynamic operation)
- Expensive... **for the time being**



Cost of a PEM electrolyzer stack



Strategy for coating stainless steel

Coatings for PEM fuel cells:

Standard approach:

Stainless steel

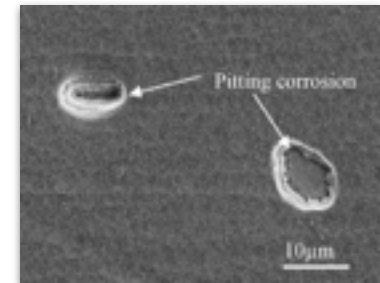
Γ 1 μm

Coating 1

Coating 2

Corrosion resistant and conductive coating on stainless steel

PVD coating of TiN



Y. Wang, D.O. Northwood, *Journal of Power Sources* 191 (2009) 483.

The Fe^{2+} released from corrosion poison the CCM

Coatings for PEM electrolyzers:

Our approach:

Stainless steel

Γ < 50 μm

Coating 1: Titanium coating by thermal spraying

Coating 2: Surface modification of Titanium

Cost reduction?

- **PEMFC:** PVD coatings alone meet the DOE requirements.
- **PEM electrolyzers:** current Ti bipolar plates have to be coated to reduce the passivation.

Dramatic cost reduction for **large area** bipolar plates \longrightarrow **Megawatt** scale

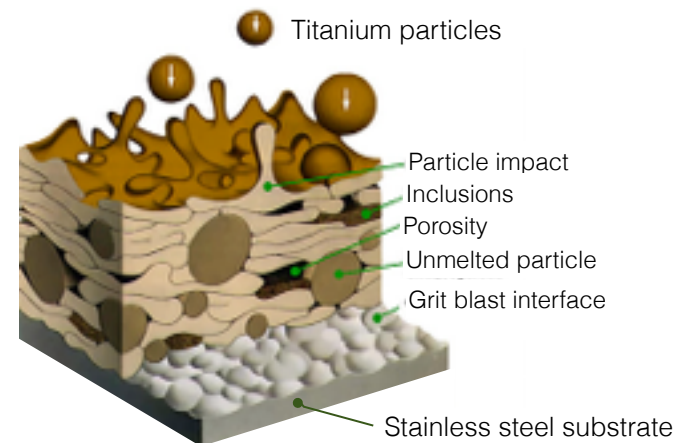
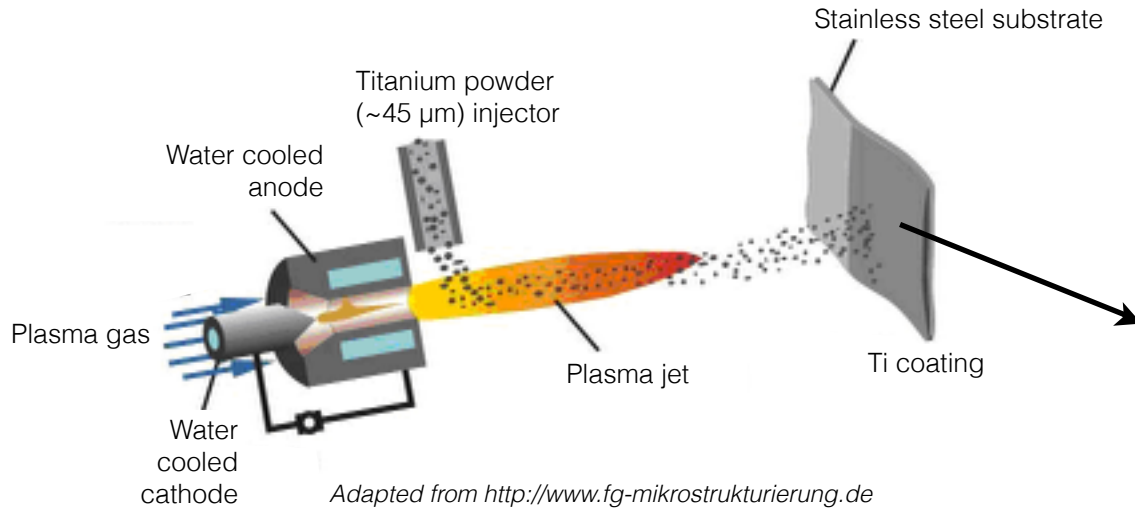
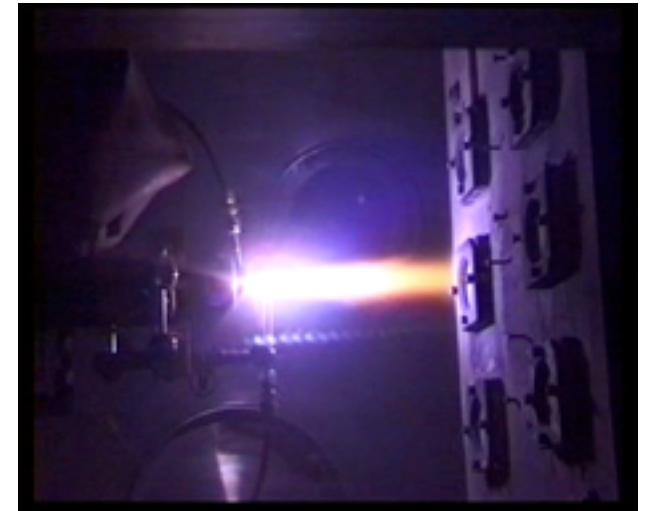


Thermal spraying

Vacuum Plasma Spraying (VPS)

Applications at the DLR:

- SOFC components
- Catalyst for alkaline electrolysis
- **Bipolar plates of PEM electrolyzers**



Deposition parameters for Ti coatings on Crofer[®] 22 APU

Sample	Input		Output		
	Powder feeder rate g min ⁻¹	Plasma enthalpy (h) MJ kg ⁻¹	Z mm	V mm s ⁻¹	Leak rate mbar l cm ⁻² s ⁻¹
CF-29	18	9.09	350	600	53
CF-30	11,7	11.1	350	600	117
CF-31	11,7	12.61	350	600	63
CF-32	11,7	14.62	350	600	48
CF-40	11,7	14,6	320	350	8.4
CF-41	11,7	14.62	320	350	12.6
CF-42	11,7	14.65	320	350	88.8
CF-56	11,7	14.6	320	350	8.4
CF-57	11,7	14.66	320	350	10.5
CF-105	11,7	21.27	320	350	4.3

Vessel Pressure: 50 mbar
 Anode type: M3-6mm
 Injector: Internal
 Track separation: 10 mm
 Number of layers: 8
 Substrate temperature: 250 °C

Plasma enthalpy

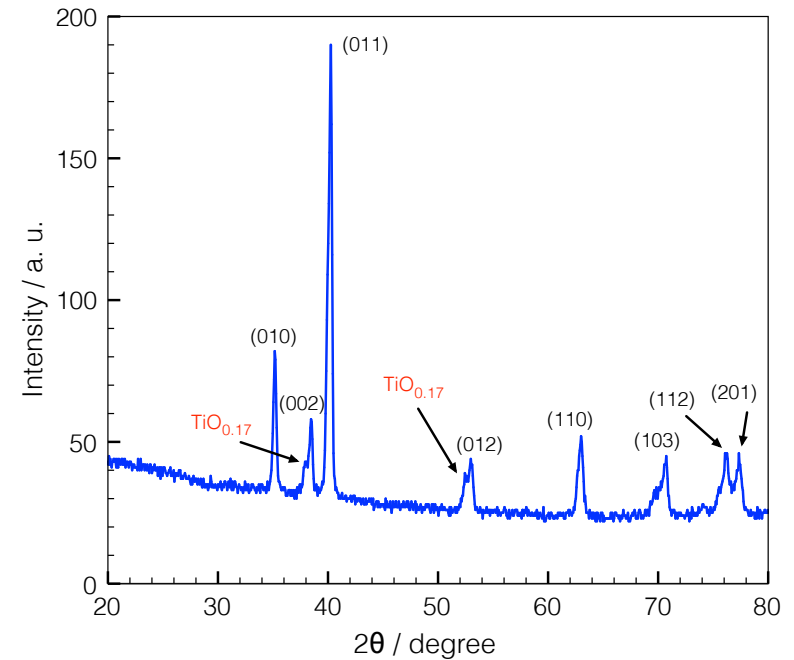
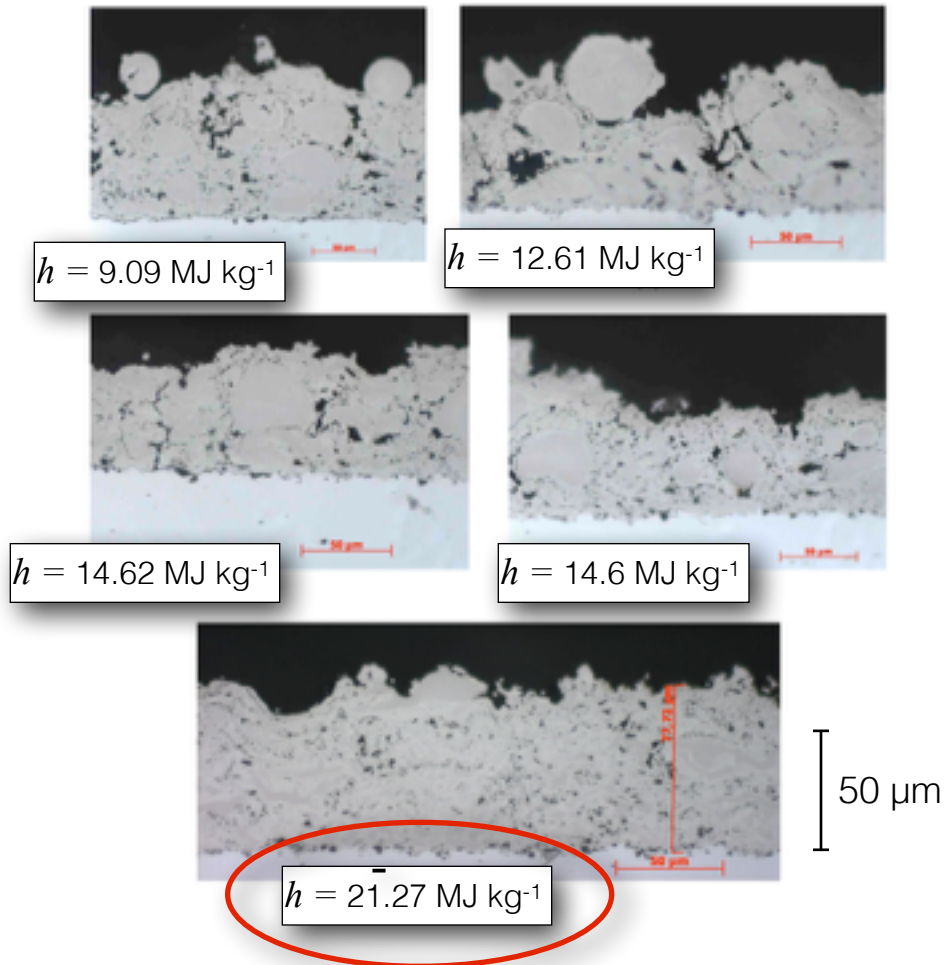
$$h = P_{\text{eff}} / m_g \text{ (MJ kg}^{-1}\text{)}$$

↓ ↓
 Power dissipated Plasma gas flow
 in the gas (kW) rate (kg s⁻¹)

P. Fauchais, J. Phys. D: Appl. Phys. 37 (2004) R86.



Coating development

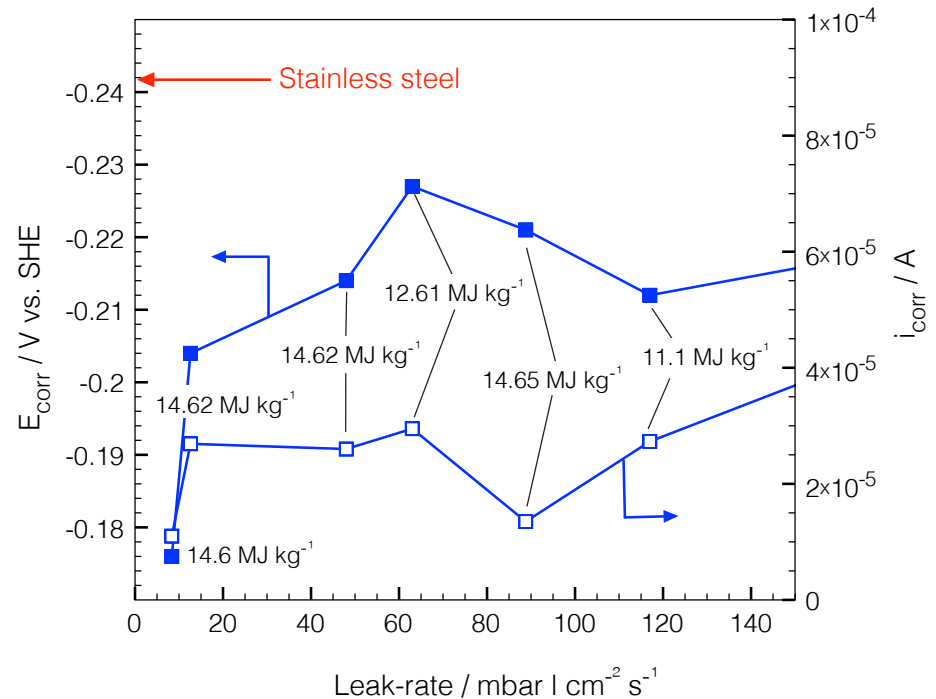
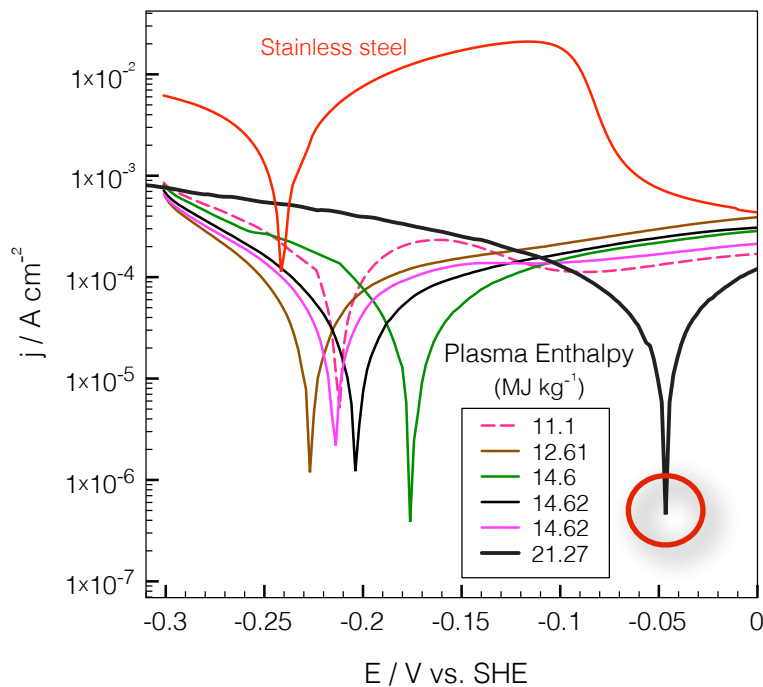


- Dense coatings of Ti were produced with high plasma enthalpies.
- Pure Ti- α was obtained as the deposition was performed in vacuum.



Electrochemical characterization

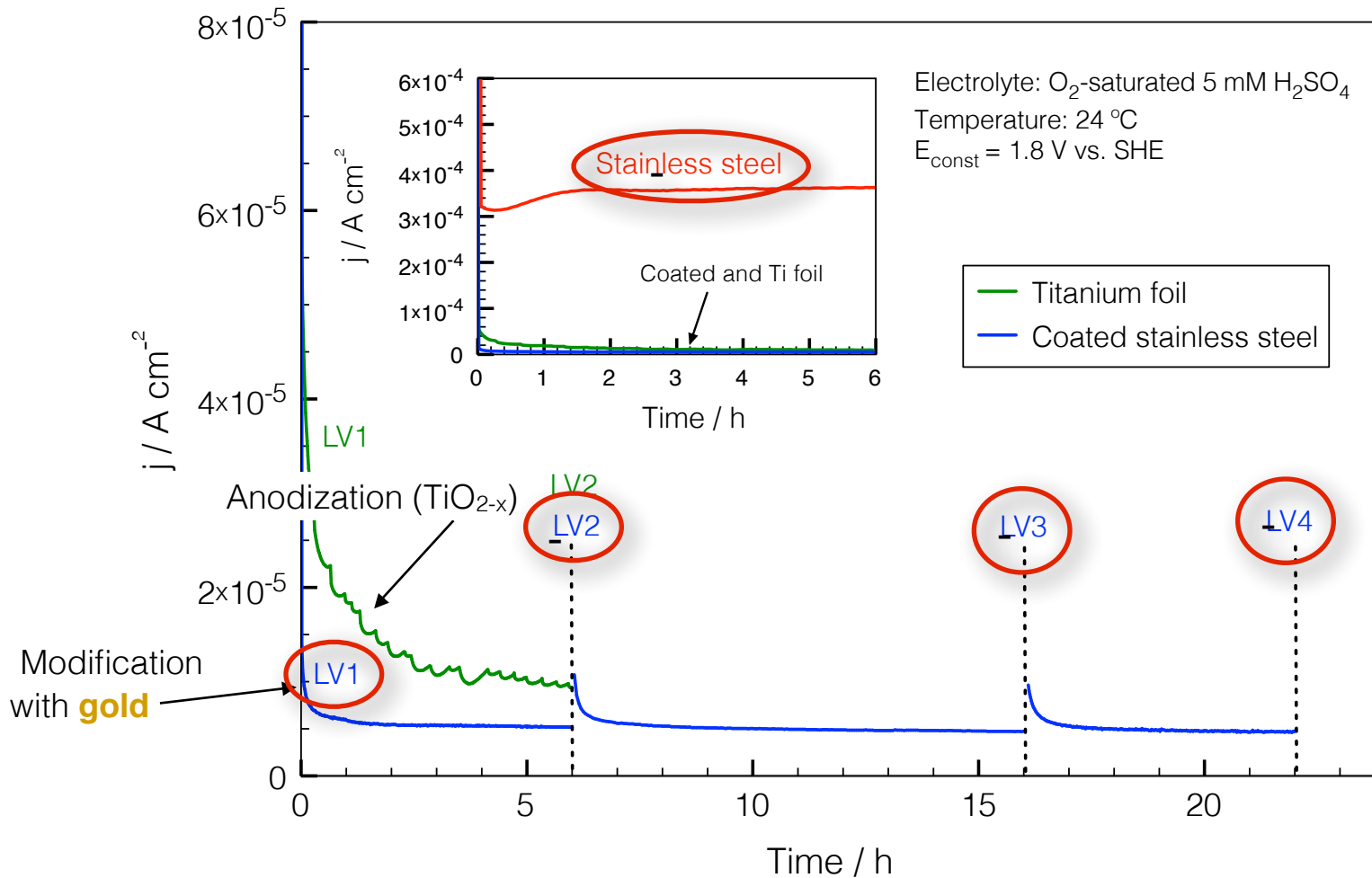
Experimental conditions: O₂-saturated 0.5 M H₂SO₄, temperature: 24 °C, scan rate: 5 mV s⁻¹



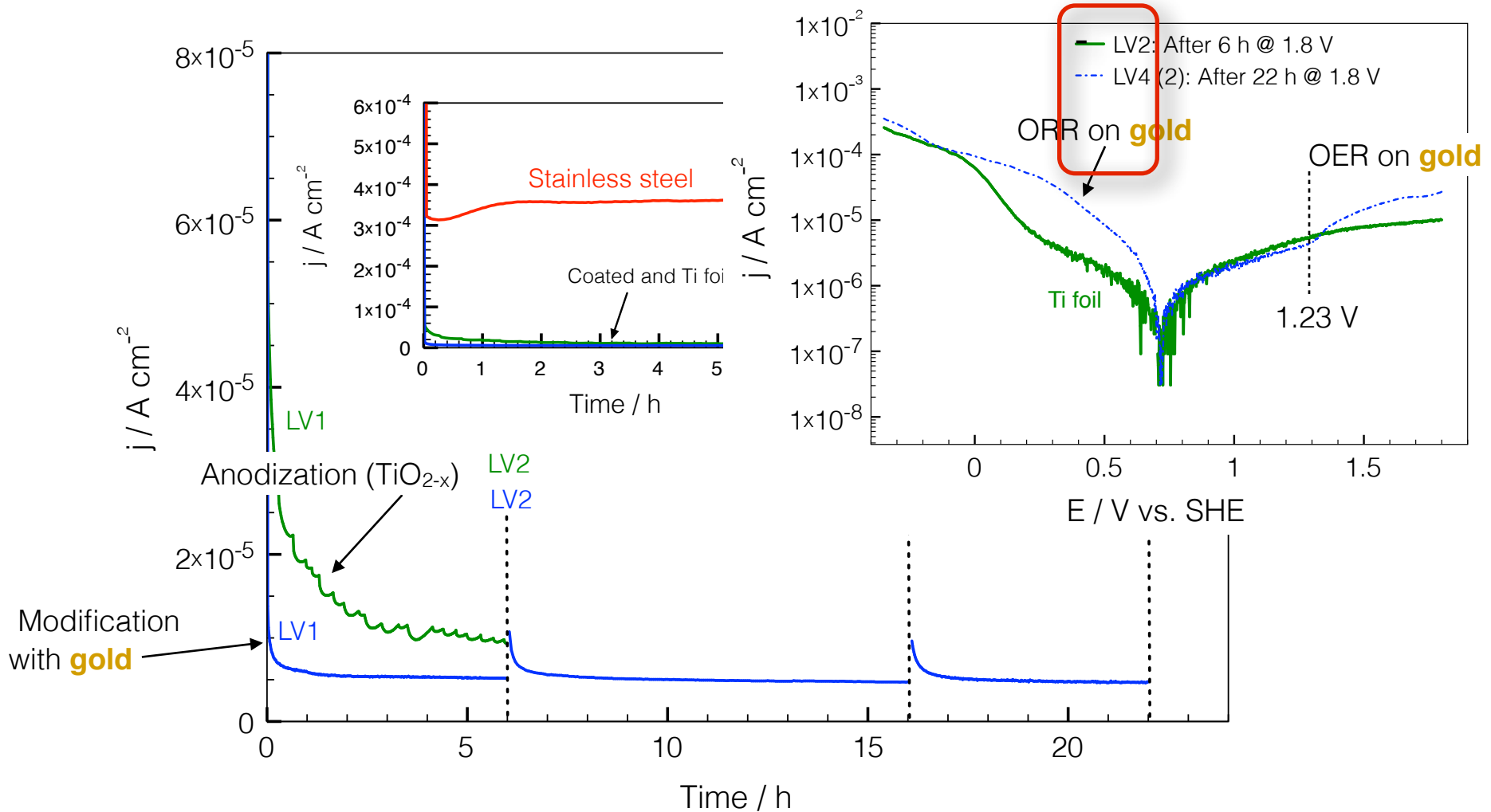
- Ti coatings deposited with high plasma enthalpies showed lower corrosion currents (i_{corr}) and higher corrosion potentials (E_{corr}) than stainless steel.



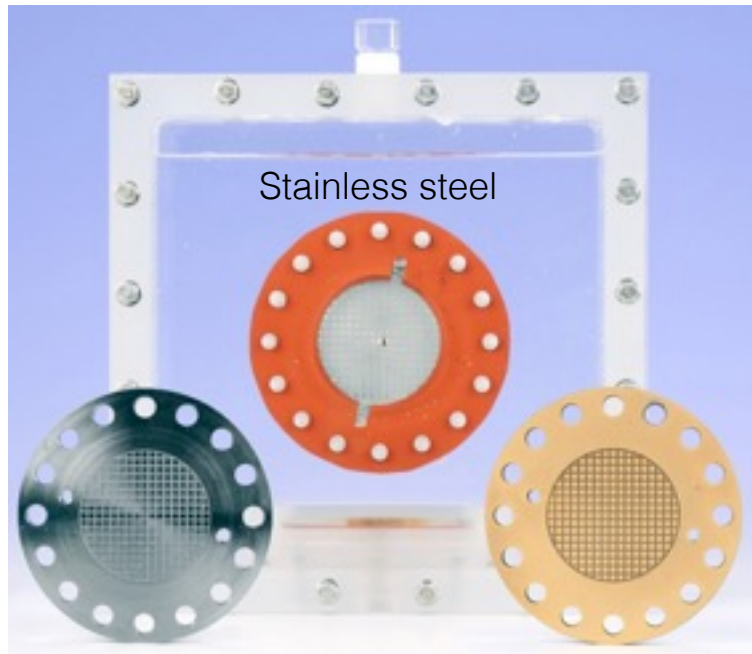
Further improvement of the coating



Further improvement of the coating

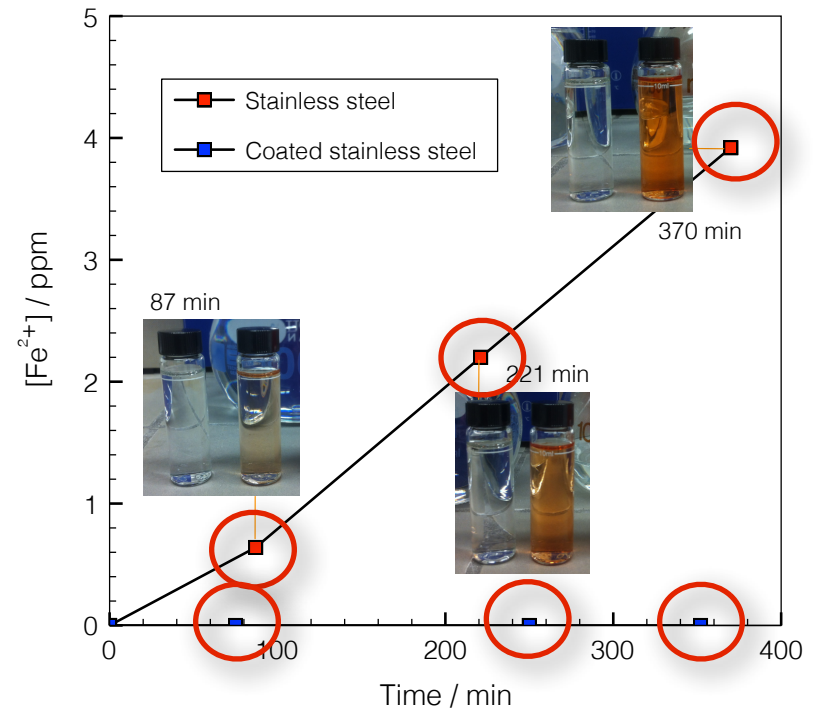


Corrosion demonstrator (measurement of Fe^{2+})



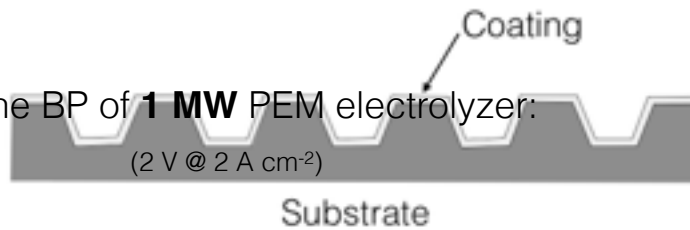
Titanium

Coated stainless steel



Cost of coating the BP of **1 MW** PEM electrolyzer:

(2 V @ 2 A cm⁻²)



1000 cm²

= 2.3 € / bipolar plate

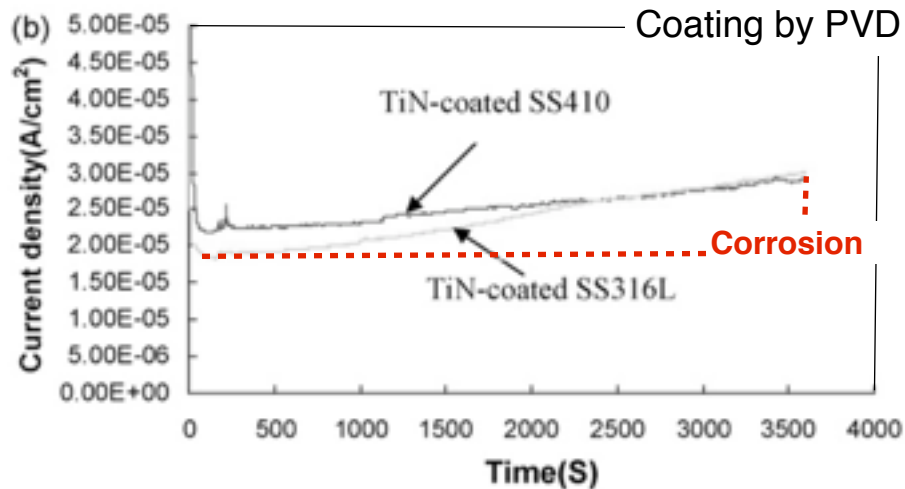
+ diverse costs. The stainless steel with flow channels is not included.



One-to-one comparison (AST for bipolar plates)

Simulated cathode of a PEMFC:

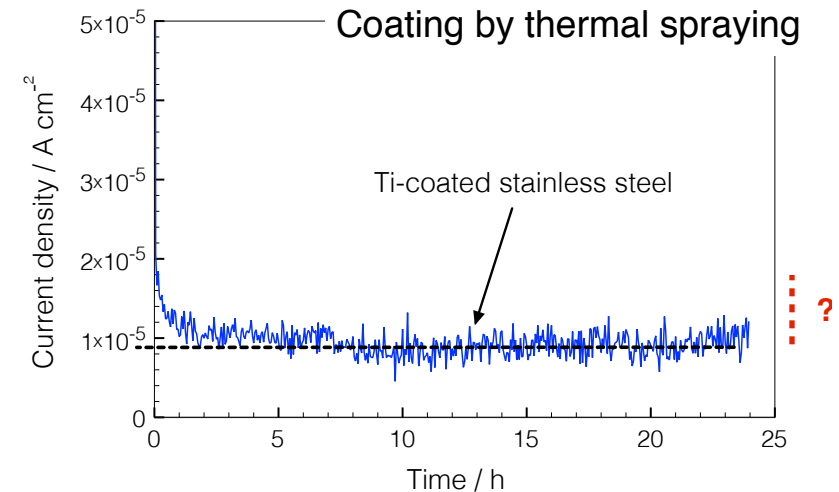
- Electrolyte: O₂-saturated 0.5 M H₂SO₄ (pH =0)
- Temperature: 70 °C
- E_{const} = 0.84 vs. RHE
- Duration of the experiment: 1 hour



Y. Wang, D.O. Northwood, *Journal of Power Sources* 191 (2009) 483.

Simulated anode of a PEM Electrolyzer:

- Electrolyte: O₂-saturated 0.5 M H₂SO₄ (pH =0)
- Temperature: **80 °C**
- E_{const} = **2 V** vs. RHE
- Duration of the experiment: **24 hours**



- No pinholes (SEM not shown).
- No corrosion of the substrate.



Conclusions

- There is an urgent need to reduce the cost of PEM electrolyzers for Power-to-Gas applications. The bipolar plates are very expensive.
- Dense Ti coatings were produced by plasma spraying (with high h) on stainless steel substrates.
- The coatings were evaluated in simulated conditions: **O₂-saturated 0.5 M H₂SO₄, 80 °C, E_{const} = 2 V.**
- Further improvement of the coating resulted in full protection of the substrate over extended periods of time (**demonstrated!**).
- The cost of coating stainless steel bipolar plates of 1000 cm², for the MegaWatt range, is estimated in 2.3 € per piece.



Thank you for your attention

